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TITLE: REFRIGERATOR-COOLED CRYOSTATS FOR RESEARCH ON INERTIAL CONFINEMENT FUSION

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Abstract

In order to utilize the increased density of liquified or solidified DT fuel, one must provide means for cooling fusion targets to the range 15 K to 25 K. The heat loads at these low temperatures can be kept modest by providing adequate thermal shielding maintained near 75 K. Modern closed-cycle-helium refrigerators, operating on the Gifford-McMahon cycle, provide for both thermal loads reliably and inexpensively, thanks to the increasing implementation of the commercial cryopump. By adding a large sealed can containing helium exchange gas to the second stage of the refrigerator, we create a nearly ideal environment for cryogenic fusion targets. We discuss the design and operation of two separate apparatus. One has been used almost continuously over the past two years for various inertial confinement fusion studies.
REFRIGERATOR-COoled CRYOSTATS FOR RESEARCH ON INERTIAL CONFINEMENT FUSION

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INTRODUCTION

It is becoming clear that cryogens is a valuable tool for inertial confinement fusion. While the use of cryogenics has been steadily increasing over the years, particularly for large-scale targets, the inherent difficulties associated with cryogenics are often significant.

Liquid helium, relatively inexpensive to store and transport as a cryogen, is required to provide cooling to the nuclear reaction chamber. However, providing the target with the necessary cooling is generally not straightforward without overcoming a number of technical problems. Many of these problems can be compounded by utilizing a closed cycle refrigerator as the cryogenic cooling agent.

CONCLUSION

Before discussing the advantages of using cryogenics for inertial confinement fusion research, we must consider the inherent difficulties associated with cryogenics. These difficulties include the need for cryogenic storage facilities, the cost of cryogenics, and the technical challenges associated with cryogenics. Despite these difficulties, cryogenics remain an important tool for inertial confinement fusion research.
combined temperature baths and heat exchange systems. Heat gradients in the bulk of the sample are limited by the use of super-heated noble gas exchange systems. These systems reduce radiation and enhance significantly reduce the heat leak to the He bath. The experimental sample is cooled by either using a heat switch or by admitting He exchange gas to the sealed can. The can must then be evacuated if it is desired to change the sample temperature to levels significantly above or below the He bath temperature. Optical access is accomplished by sealing fused quartz or sapphire windows into all the sealed cans. Likewise, optical access from above or below could be achieved. Thus, such a cryostat in principle could be used to cool an IC target to near 20 K and to expose it to bursts of laser radiation. One must necessarily address the problems of the limited lifetime of the liquid He bath, purchase, transport, and storage of the cryogens, and the transfer of the cryogens into the cryostat. However, a more significant problem is that the target generally cannot be cooled directly with a contact heater because that would affect the target symmetry. The target would have to be heated indirectly or be enclosed in yet another exchange gas can.

In the von Neumann stellarator, the system was designed for high-temperature studies in support of the low-temperature I-1 program. It has been in continuous use over the past 15 years to a variety of tasks, including studies of filling procedure for prototype cryostat target and direct observation of contact core, induction of solidifying and solidifying the core, and the liquid core, and solidifying the core, the liquid core using an optical, and solidifying the core. The liquid core was an optical path, in the optical path, in the target, the target, a target.
Stage temperature is typically about 10°C. When the second stage thermal shield is properly superinsulated, the second stage has a measured capacity of 10°C at 20°C and reaches its under no-load conditions. Hence, however, about 25 kg of copper hangs on the second stage and the apparatus is limited to 10°C. Most of this mass is in the form of a "cold plate" by which internal dimensions of 5.5 cm diameter x 2.5 cm long, thus space is filled with 4He gas at a pressure of 290 torr at 20°C. The top of this can, known as the "cold plate", extends outwards to about one centimeter thick, and about one centimeter thick, and the exchange gas is at least 1°C to the cold top. After rendering the interior more isothermal, this was apparently been successful - separate thermometers at the top-bottom, and sides of the cold can all agree within 0.05°C at 20°C. A heater is wrapped around the second stage of the refrigeration to achieve closed cycle temperature control at the cold can. Operation to within 0.1°C is routinely achieved, after turning on the cooling water for the compressor. One could use an oil cooled compressor, and then switching on the compressor, the apparatus cools from room temperature to below 0°C in about 9 hours. Warm up is much slower unless aided by heating ports into the annular space with exchange gas.

Closed cycle helium refrigerators were developed to a high degree of reliability by the cryogenic industry. There are many suppliers, both domestic and foreign, all offering units of varying quality, high reliability, low maintenance, prompt service, and reasonable cost. The experience supports the excellent service record of these units, as we have had no problems with either the refrigeration cold head or compressor, or a third party source with adequate cycles and temperature control. To summarize, the rate of temperature control should be much higher than the rate of temperature change of the sample.
such as used here. It is precisely the large working volume of the helium-filled cold can which makes this type of cryostat uniquely suited to IIF studies.

Unattended operation for long periods of time is one of the major advantages of a cryostat of this type. Our long-term experiments in liquid and solid T_{2} and D_{2} would not have been possible without this valuable feature. In one experiment, we followed the crystalline growth pattern in a sample of frozen H_{2} for over a two week period.

Although our cryostat incorporates optical access via four sets of fused silica windows at 90° angles, in its present form it is not suitable for multiple-beam implosion studies on actual ICF targets. To do so, the beams or beam pipes would have to be integrated into the design of the cryostat. Nonetheless, the cryogenic concepts utilized here would be applicable to such an integrated design. Fig. 5 shows such a design, where hemispherical windows would allow converging beams from a wide solid angle to impinge on the target. The large working volume of approximately 10^{-3} L would permit the installation of optics necessary for direct-drive targets, as well as helium/argon assemblies for indirect drive studies.

REFERENCES:


Figure 1. A conventional optical cryostat cooled with liquid cryogens.
Figure 2. A refrigerator–cooled optical cryostat.
Figure 3. A refrigerator–cooled cryostat for inertial confinement fusion physics.
REFRIGERATOR-COOLED CRYOSTATS FOR RESEARCH ON INERTIAL CONFINEMENT FUSION

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SUMMARY

Cryogenics is a valuable tool for conducting research on inertial confinement fusion prototype targets. The increase in density in the DT fuel afforded by cryogenic temperatures cannot be easily matched in room-temperature designs. To achieve a density in DT equal to the liquid density at the triple point, a room-temperature pressure of just over 3 kbar (44,550 psi) is necessary. Main cryogenic problems can be circumvented by utilizing a closed-cycle helium refrigerator as the cooling agent.

A conventional constant-cooled by liquid cryogens could be used to cool an ICF target to near 3 kbar and to expose it to burst of laser radiation. One must necessarily address the problems of the limited lifetime of the liquid.He bath, the purchase, transport and storage of the cryogens as well as the hazards of transfer of the cryogens into the cryostat. However, a significant problem is that the target generally cannot be heated directly with a contact heater because that would affect the target symmetry.

We have built two separate cryostats each cooled by a closed-cycle helium refrigerator operating on the Gifford-McMahon cycle. The design of both cryostats is presented, and the operation of one of them is discussed thoroughly. No liquid cryogens are needed.

This type of refrigerator has been developed to a high degree of reliability by the cryogenics industry. Our experience supports the conclusion that the use of this closed-cycle refrigerator is feasible even in ICF experiments. To be able to operate the cryostat at the higher temperatures, the apparatus is liquid nitrogen-cooled. Without the coilable feature, it would not have been possible without the valuable feature.